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## (54) Audible noise reducing.

(57) A system for reducing audible noise in a stereo receiver includes a stereo demodulator (11) having a monophonic signal output and a difference signal output. A left signal combiner (12) and a right signal combiner (14) are provided. At least one filter (21), having a controllable variable cutoff frequency, intercouples at least one of the difference signal output and the monophonic signal output with the left (12) and right (14) combiners. A control signal generator (22) has a control signal output (26) coupled to the control signal input of the variable cutoff frequency filter.

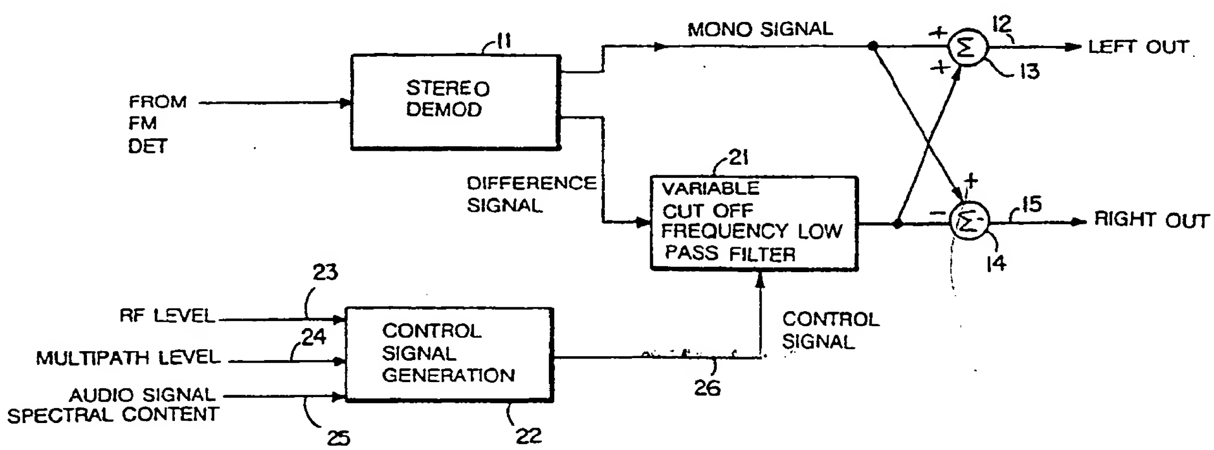


FIG. I

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# AUDIBLE NOISE REDUCING

The present invention relates in general to audible noise reducing in stereo broadcasts characterized by improved audible noise reduction not only in weak sigral areas, but also under strong signal conditions, such as occur in the presence of multipath transmission without reducing stereo separation to the extent that occurs with conventional blending circuits.

In conventional FM stereo broadcasting the sum of left and right audio signals modulate the main carrier sigral to provide a compatible monophonic audio signal. The difference between the left and right audio signals modulates a 38 kHz subcarrier to create a double sideband suppressed carrier signal that also modulates the carrier along with a 19 kHz pilot carrier used in the receiver to detect the different signal.

In the receiver the sum of the monophonic signal and the difference signal provide the left signal and the difference provides the right signal.

Noise added to the RF signal during transmission and in the receiver causes added noise at the FM detector output of the receiver with a spectrum that rises with frequency. Thus, the low frequency (under 15 kHz) monophonic signal is much less affected by noise than the high frequency (23-53 kHz) difference signal channel. Therefore, noise in the difference channel produces most of the audible noise at the output of a stereo receiver.

Typical FM stereo receivers, especially those used in mobile applications, include a blend circuit that reduces the level of the difference channel audio signal as audible noise increases. Although this circuitry reduces audible noise, it also reduces stereo separation. Typically this circuitry reduces gain in the different signal channel as received RF level decreases. Above a certain RF level, the difference channel gain does not change. Below that RF level, the difference signal clannel gain decreases to reduce the audible noise. Below a still lower RF level, the difference signal clannel gain is zero, resulting in monophonic reproduction of the stereo broadcast. Thus, the perceived audible noise level remains substantially constant during this transmission. However, stereo separation regressively decreases. Other criteria for controlling the gain of the difference signal channel may also be used. It is recognized that out-of-band noise; that is, noise at the FM detector output having spectral components above 100 kHz, is a good indicator of multipath conditions. A paper entitled "A Theoretical and Experimental Study of Noise and Distortion in the Reception of FM Signals" by Amar G. Bose and William L. Short, MIT Research Laborabory of Electronics Technical Report No. 540, demonstrates that multipath transmission causes greater noise and distortion in the higher frequency difference signal channel than in the audio monophonic channel. Thus, reducing gain in the difference signal channel upon sensing an increase in out-of-band noise may reduce the audible effect of multipath transmission, but at the expense of reduced stereo separation. Furthermore, the system may transmit noise that is audible because there is no audio signal of sufficient intensity to mask the noise.

According to the invention, the detected difference signal is applied to a low pass filter, and the output of the low pass filter is combined with the monophonic or sum signal to provide the left and right signals. The cutoff frequency of the low pass filter is adjusted dynamically to reject the noise spectral components above the cutoff frequency present in the detected difference frequency while allowing spectral components below the cutoff frequency to be combined with the sum signal and maintain good stereo separation while significantly reducing audible noise.

The cutoff frequency of the low pass filter may be adjusted in accordance with one or more parameters to provide a cutoff frequency control signal applied to the low pass filter to control the cutoff frequency.

According to one aspect of the invention cutoff frequency may be set in accordance with the detected level of the RF signal by reducing the cutoff frequency with decreasing RF level.

According to another aspect of the invention, the cutoff frequency may be varied in accordance with the audio spectral components then being broadcast to take advantage of the psychoacoustic phenomenon of masking. When an audio signal spectral component is present at higher level than a corresponding noise spectral component, the audio signal masks the noise component, making it inaudible. By controlling the cutoff frequency to the highest frequency at which the audio signal spectral components exceed the levels of noise spectral components, the noise will not be audible. This approach results in considerably higher noise levels present without the noise being audible. The level of audio signal spectral components may be sensed in the monophonic signal channel or the difference signal channel, or combinations thereof. Sensing in the difference channel is preferable.

According to still another aspect of the invention, the cutoff frequency may be varied in accordance with the level of multipath interference, for example by reducing the cutoff frequency with increasing level of out-of-band noise spectral com-

ponents.

According to another aspect of the invention, it is advantageous to include an all-pass filter in the monophonic channel with a cutoff frequency corresponding to that of the low pass filter of order and Q the same as that of the low pass filter so that the phase shift introduced by both filters is the same at all audio frequencies to attain reduction of audible noise while maintaining good stereo separation.

The invention has a number of advantages. It reduces audible noise under strong signal conditions and without reducing stereo separation for spectral components within the passband.

Numerous other features and advantages of the invention will become apparent from the following specification when read in connection with the accompanying drawing in which:

FIG. 1 is a block diagram illustrating the logical arrangement of an embodiment of the invention having a low pass filter with variable cutoff frequency in the difference signal channel;

FIG. 2 is a variation of the embodiment of FIG. 1 also including an all-pass filter in the monophonic channel having a variable cutoff frequency;

FIG. 3 is a graphical representation of stereo separation as a function of frequency for a given control voltage for the systems of FIGS. 1 and 2;

FIG. 4 is a block diagram illustrating the logical arrangement of a control signal generator responsive to the out-of-band noise level and the audio spectral content of the detected different signal;

FIG. 5 is a schematic circuit diagram of an exemplary all-pass filter with controlled cutoff frequency;

FIG. 6 is a schematic circuit diagram of an exemplary low-pass filter with controlled cutoff frequency;

FIG. 7 is a schematic circuit diagram of an exemplary combiner;

FIG. 8 is a schematic circuit diagram of an exemplary 100 kHz high pass filter and level detector;

FIG. 9 is a schematic circuit diagram of a 6 kHz high-pass filter and level detector; and

FIG. 10 is a schematic circuit diagram of an exemplary combiner of FIG. 4.

With reference now to the drawing and more particularly FIG. 1 thereof, there is shown a block diagram illustrating the logical arrangement of an embodiment of the invention. The invention includes a conventional stereo demodulator 11, a left combiner 12 that adds the monophonic signal and difference signal to provide the left output signal on line 13 and a right combiner 14 that subtracts the difference signal from the monophonic signal to provide the right output signal on line 15. In addition the invention includes a variable cutoff frequency low pass filter 21 intercoupling the difference signal output of stereo demodulator 11 and left and right combiners 12 and 14. Alternatively, but less preferable, filter 21 could be a high cut shelf filter that may pass spectral components above cutoff, but with significant attenuation. A control signal generator 22 responds to an RF level signal on line 23, a multipath level signal on line 24 and an audio signal spectral content signal on line 25 to provide a control signal on line 26 that is applied to variable cutoff frequency low pass filter 21 to cause the cutoff frequency to decrease with decreasing RF level, increasing multipath level and decreasing audio signal spectral content.

Referring to FIG. 2, there is shown a variation of the embodiment of FIG. 2 in which variable cutoff frequency all-pass filter 31 is connected between the monophonic signal output of stereo demodulator 11 and left and right combiners 12 and 14. Control signal generator 22 controls the cutoff frequencies of all-pass filter 31 and low pass filter 21 to be the same, and both filters are characterized by the same Q and order so that the phase shift introduced by both filters to transmitted spectral components is substantially the same to maintain good stereo separation for the transmitted spectral components.

Referring to FIG. 3, there is shown a graphical representation of stereo separation as a function of frequency for a given control voltage by upper curve A and lower curve B for the systems of FIGS. 1 and 2, respectively. This representation demonstrates the improved stereo separation available from the system of FIG. 2.

Referring to FIG. 4, there is shown a block diagram illustrating the logical arrangement of a suitable embodiment for control signal generator 22. The multipath level signal on line 24 is at the output of level detector 41 that provides a signal representative of the out-of-band spectral components provided by the FM detector output after transmission through 100 kHz high pass filter 42 having a cutoff frequency at substantially 100 kHz. The DC level on line 23 may correspond to the AGC signal that is representative of RF level. The audio signal spectral content signal on line 25 may be on the output of level detector 43 representative of the difference signal spectral components above 6 kHz after transmission through high pass filter 44 having a cutoff frequency of 6 kHz. Combiner 45 combines these three signals as indicated to provide the control signal on line 26 that increases with increasing RF-level, increasing the spectral components in the difference signal above 6 kHz and decreasing out-of-band spectral components on line 24 to correspondingly increase the filter

cutoff frequencies.

Referring to FIG. 5, there is shown a schematic circuit diagram of an exemplary embodiment of the all-pass filter for the all-pass filter with controlled cutoff frequency.

Referring to FIG. 6, there is shown a schematic circuit diagram of an exemplary embodiment of the difference channel low-pass filter.

Referring to FIG. 7, there is shown a schematic circuit diagram of an exemplary embodiment of combiners 12 and 14.

Referring to FIG. 8, there is shown a schematic circuit diagram of an exemplary embodiment of 100 kHz high pass filter 42 and level detector 41.

Referring to FIG. 9, there is shown a schematic circuit diagram of 6 kHz high-pass filter 44 and level detector 43 of FIG. 4.

Referring to FIG. 10, there is shown a schematic circuit diagram of an exemplary embodiment of combiner 45 of FIG. 4.

There has been described novel apparatus and techniques for reducing noise with a lesser reduction of stereo separation.

Other embodiments are within the claims.

## Claims

1. Apparatus for reducing audible noise in a stereo receiver comprising,
a stereo demodulator (11) having a monophonic signal output and a difference signal output;
a left signal combiner (12) and a right signal combiner (14);
at least one variable cutoff frequency filter (21) with a control signal input (26) and having a controllable variable cutoff frequency intercoupling at least one of the difference signal output and the monophonic signal output with the left and right combiners;
and a control signal generator (22) having a control signal output coupled to the control signal input of the variable cutoff frequency filter.

2. Apparatus according to claim wherein a first variable cutoff frequency filter is a low pass or high cut shelf filter intercoupling the difference signal output with the left and right signal combiners (12,14).

3. Apparatus according to claim 2, further comprising at least a second variable cutoff frequency filter (31) intercoupling the monophonic signal output with the left and right combiners (12,14) and having a control signal input coupled to the control signal output of the control signal generator (22).

4. Apparatus according to claim 3, wherein the cutoff frequencies of the filters (21,31) are substantially the same.

5. Apparatus according to claim 4, wherein the filters impart substantially the same phase shift to audio spectral components transmitted therethrough.

6. Apparatus according to any of claims 1 to 5, wherein the control signal generator (22) comprises at least one high pass filter (42,44) with an input and an output and at least one level detector (41,43) having an input coupled to the associated high pass filter output and an output coupled to the control signal output (26), the or each high pass filter input being coupled to one of the monophonic signal output and the difference signal output.

7. Apparatus according to claim 6, wherein a first high pass filter (44) has a cutoff frequency at an audio frequency above 1 kHz and sufficiently low to pass audible noise spectral components with its input coupled to the difference signal output.

8. Apparatus according to claim 6, wherein a high pass filter (42) has a cutoff frequency at radio frequency sufficiently low to pass spectral components characteristic of multipath reception, with its input coupled to the monophonic signal output.

9. Apparatus according to claim 7, wherein a second high pass filter (42) has a cutoff frequency at radio frequency sufficiently low to pass spectral components characteristic of multipath reception, with its input coupled to the monophonic signal output, and further comprising a combiner (45) having first and second inputs (24,25) coupled to the respective level detector outputs and an output (26) forming the control signal output.

10. Apparatus according to claim 9, wherein the combiner (45) also has a third input (23) that receives a DC level limiting the control signal on the control voltage output so that the cutoff frequency of the variable frequency filter (21,31) remains above a predetermined audio frequency.

11. Apparatus according to claim 1, wherein the control signal generator has at least one input from the group consisting of:
an input (23) for receiving a signal related to radio frequency level of the signal received by the stereo receiver,
an input (24) for receiving a signal related to multipath level characterizing the degree of multipath components in the RF signal received by the stereo receiver, and
an input (25) for receiving a signal related to audio signal spectral content in a signal applied to the stereo demodulator,
whereby the control signal on the control signal output (26) is related to the signal then on the at least one input.

12. Apparatus according to claim 11, wherein there are respective inputs for the RF level (23), the multipath level (24) and the audio signal spectral content (25).

13. Apparatus according to claim 1, further comprising a second filter (31) which is an all-pass filter

that operates within the audio frequency band, intercoupling the other of the difference signal output and the monophonic signal output with the left and right combiners (12,14).

14. Apparatus according to claim 1, wherein the receiver has an FM detector output and the control signal generator comprises (22),

a first channel having a high pass filter (42) with a super-audible cutoff frequency and a level detector (41) arranged to receive a signal from the FM detector output of the receiver representative of multipath to provide a multipath level signal representative of multipath level,

a second channel having a high pass filter (44) with a cutoff frequency in the treble audio frequency range and a level detector (43) arranged to receive a difference signal from the difference signal output to provide an audio signal spectral content level signal representative of audio signal spectral content,

and a combiner (45) having at least first (24) and second (25) inputs for receiving the multipath level signal and the audio signal spectral content level signal to provide at least a component of the control signal related to the latter level signal.

15. Apparatus according to claim 14, wherein the combiner (45) has at least a third input (23) for receiving a DC level that limits the range of variability of the cutoff frequency and forms a component of the control signal.

16. Apparatus according to claim 5, wherein the second variable frequency filter (31) comprises an inverting amplifier having an input at the inverted output for receiving the control signal and coupled to a second amplifier by an emitter follower circuit.

17. Apparatus according to claim 5, wherein the low pass filter (21) comprises at least one inverting amplifier having an output coupled to an input for receiving the control signal and coupled to its output by at least one emitter follower circuit.

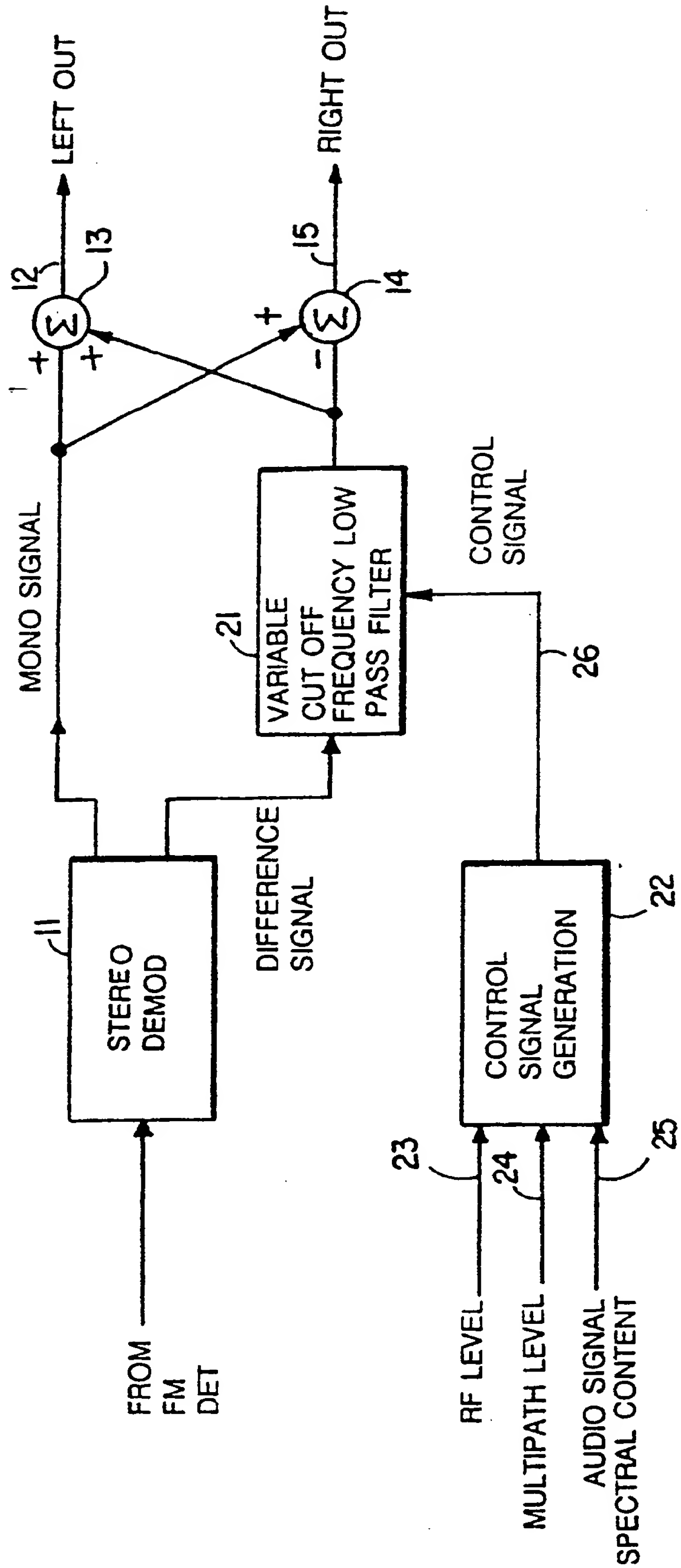

LEFT OUT
RIGHT OUT
12
13
15
14
+
+
+
−
MONO SIGNAL
21
VARIABLE
CUT OFF
FREQUENCY LOW
PASS FILTER
CONTROL
SIGNAL
26
11
STEREO
DEMOD
DIFFERENCE
SIGNAL
CONTROL
SIGNAL
GENERATION
22
23
24
25
FROM
FM
DET
RF LEVEL
MULTIPATH LEVEL
AUDIO SIGNAL
SPECTRAL CONTENT

FIG. I

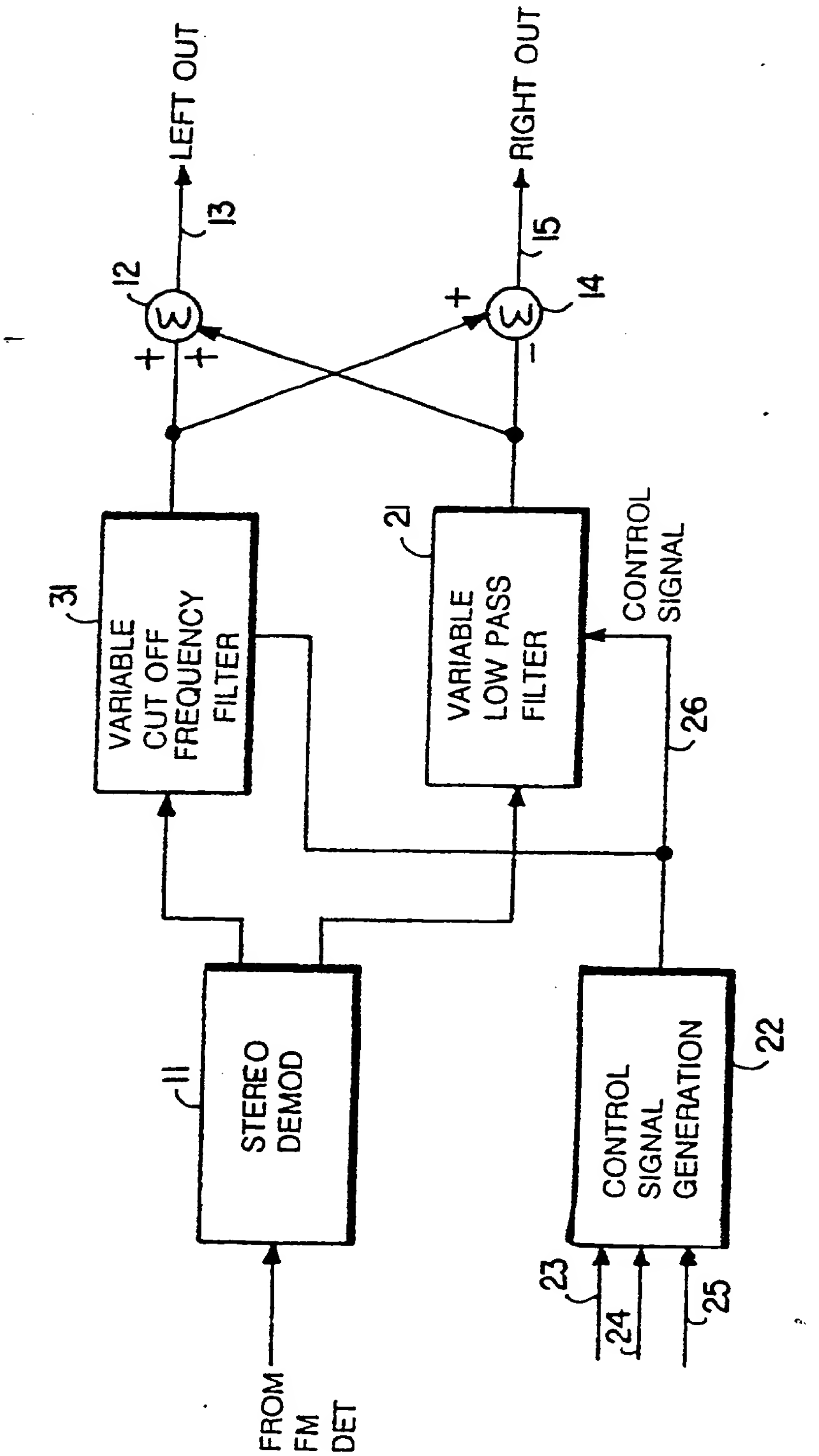
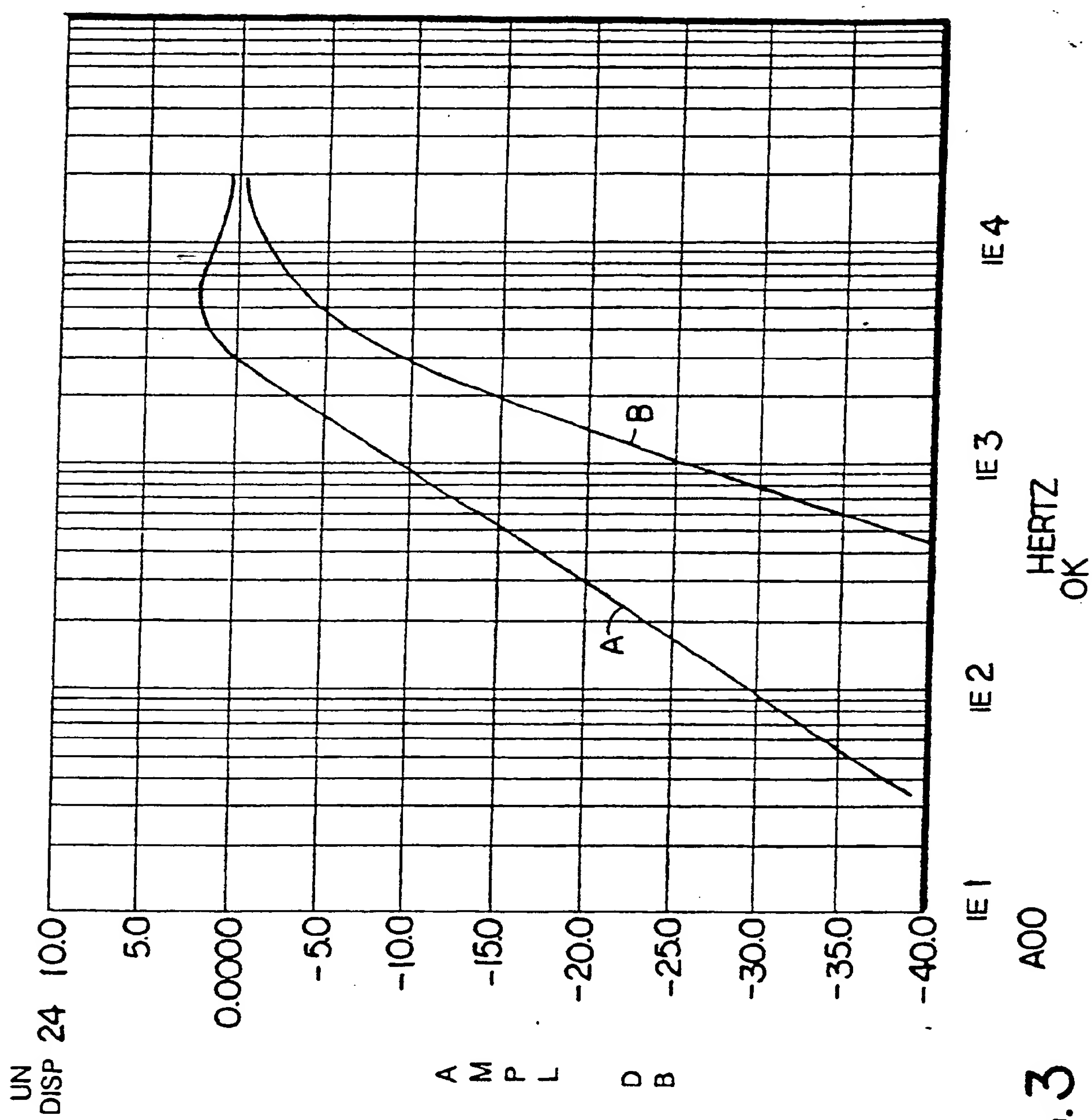

LEFT OUT
RIGHT OUT
13
12
15
14
+
+
+
−
VARIABLE CUT OFF FREQUENCY FILTER
31
VARIABLE LOW PASS FILTER
21
CONTROL SIGNAL
26
STEREO DEMOD
11
CONTROL SIGNAL GENERATION
22
23
24
25
FROM FM DET

FIG. 2


UN
DISP 24
AMPL
DB
10.0
5.0
0.0000
-5.0
-10.0
-15.0
-20.0
-25.0
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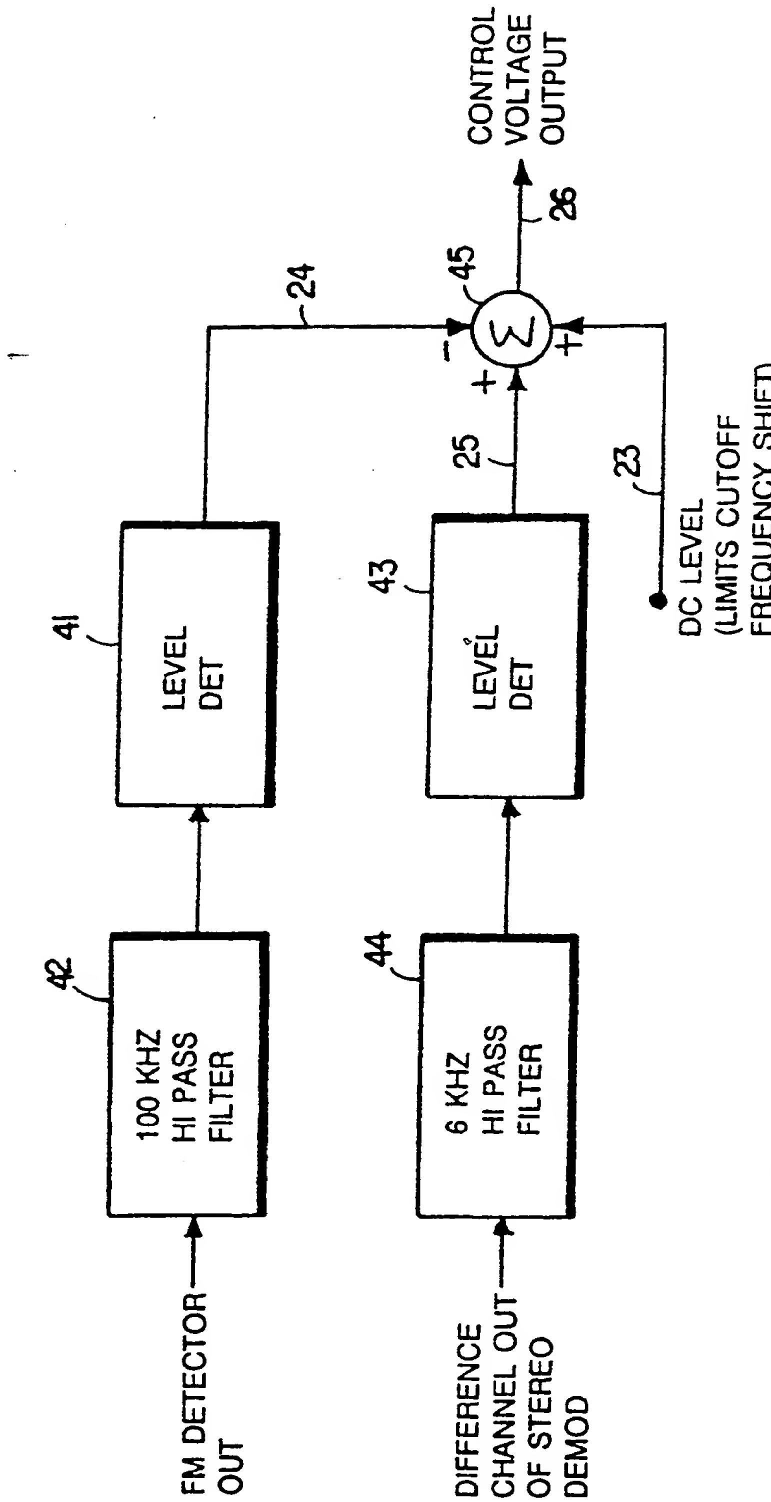
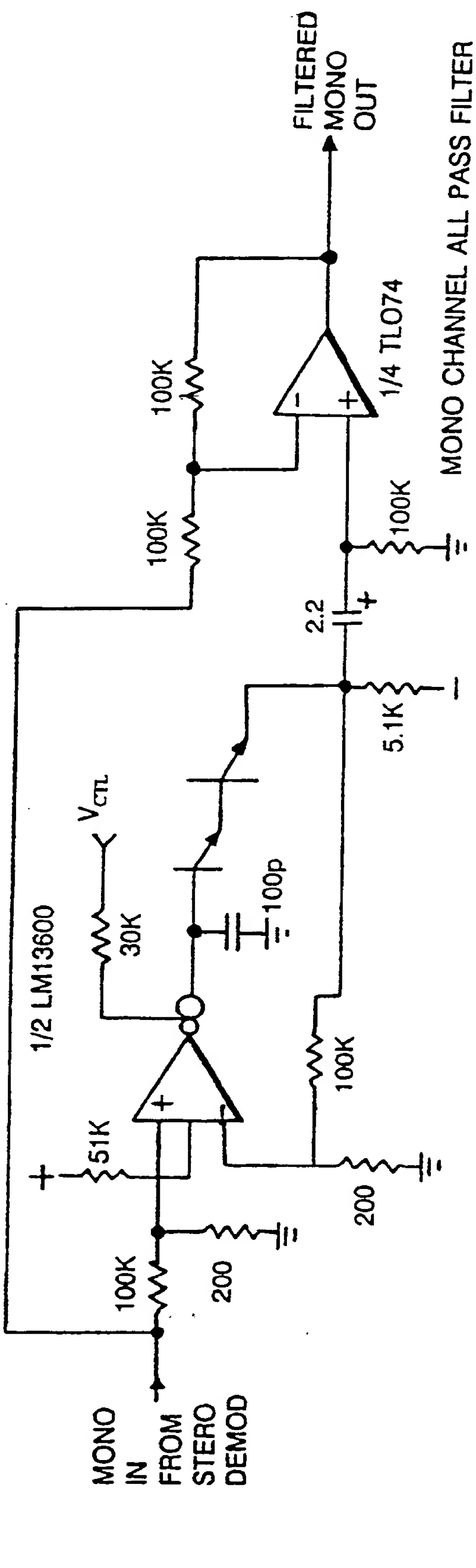
-40.0
A00
IE 1
IE 2
IE 3
IE 4
HERTZ
OK
A
B

FIG. 3



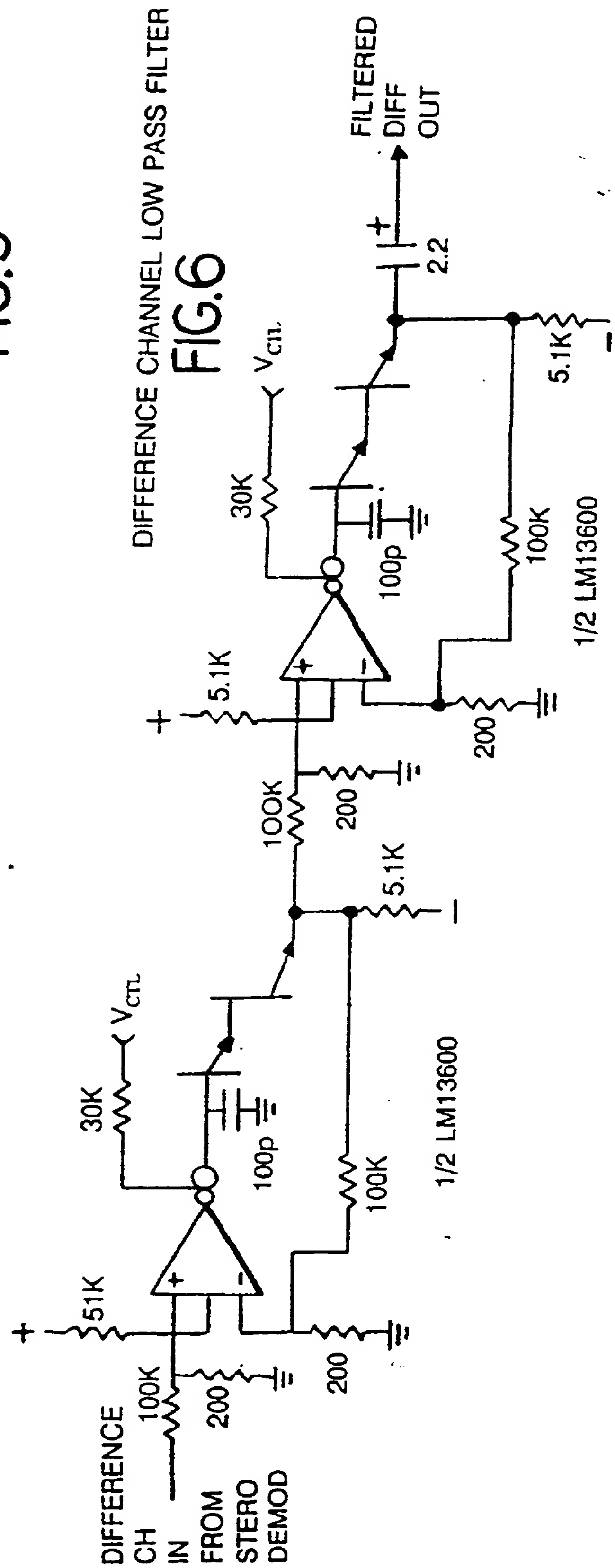

CONTROL VOLTAGE GENERATOR

FIG. 4




MONO CHANNEL ALL PASS FILTER

FIG.5




DIFFERENCE CHANNEL LOW PASS FILTER

FIG.6

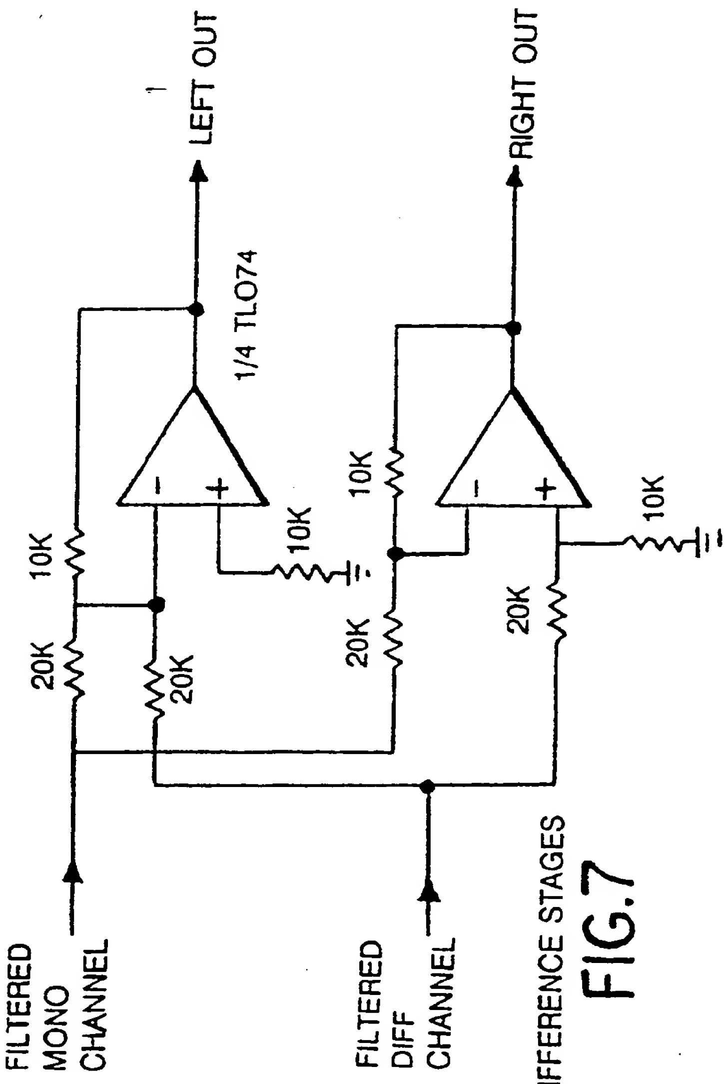



FIG.7

SUM AND DIFFERENCE STAGES

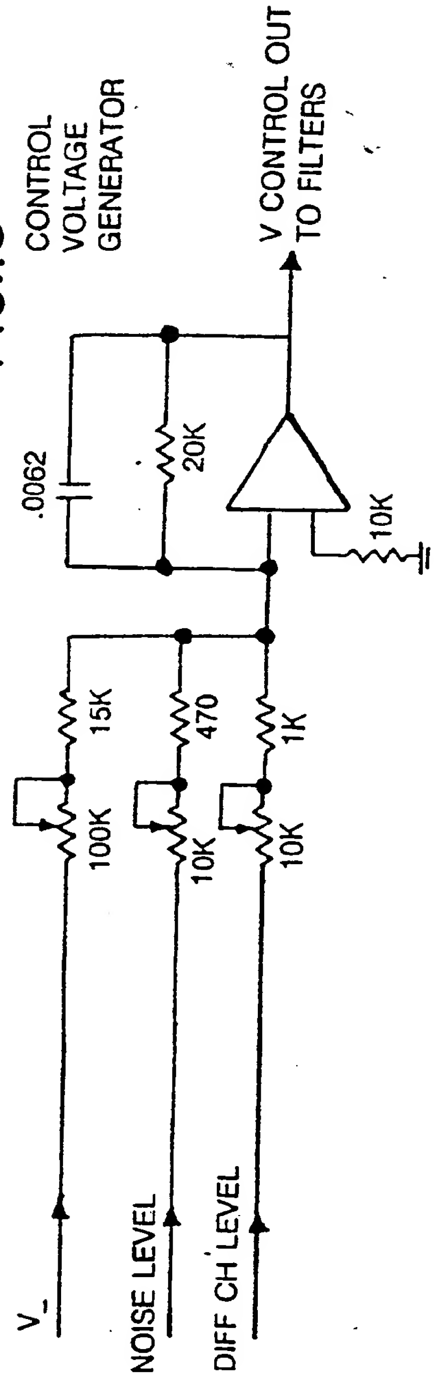



FIG.10

CONTROL VOLTAGE GENERATOR

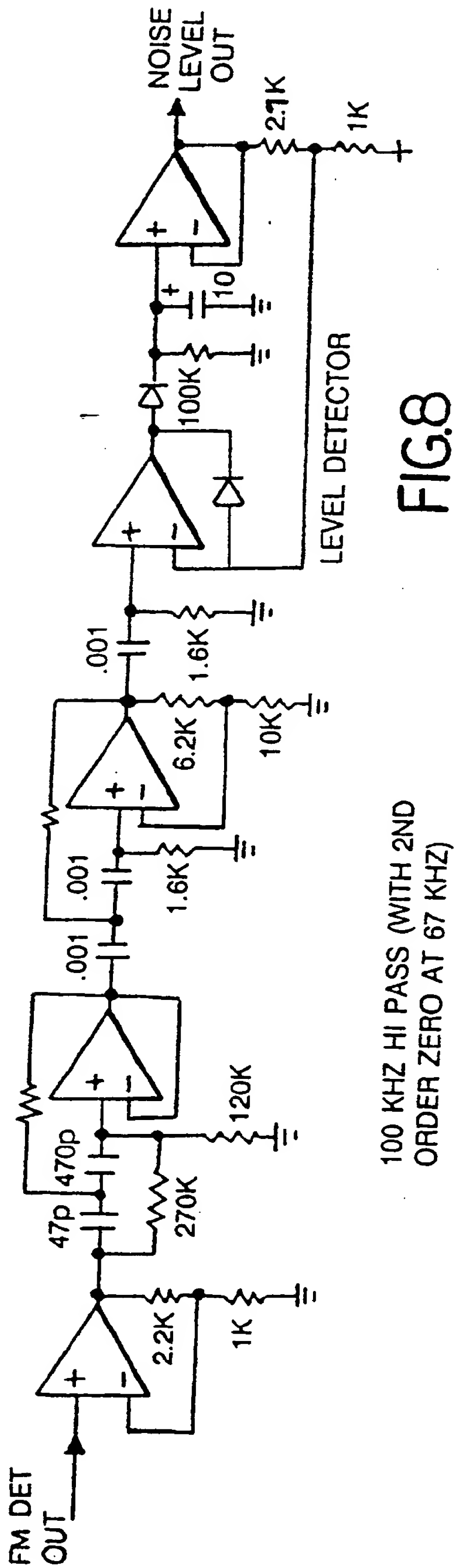

FM DET OUT
2.2K
1K
47p
470p
270K
120K
.001
.001
1.6K
6.2K
10K
.001
1.6K
100K
10
2.1K
1K
NOISE LEVEL OUT
LEVEL DETECTOR
100 KHZ HI PASS (WITH 2ND ORDER ZERO AT 67 KHZ)

FIG.8

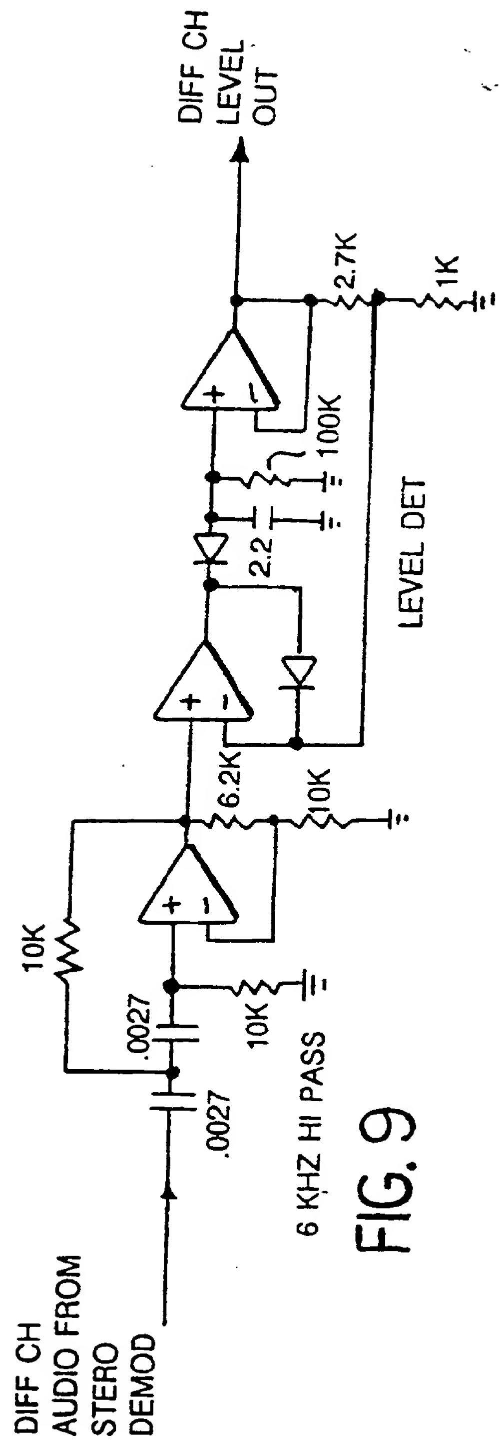

DIFF CH AUDIO FROM STERO DEMOD
.0027
.0027
10K
10K
6.2K
10K
2.2
100K
2.7K
1K
LEVEL DET
DIFF CH LEVEL OUT
6 KHZ HI PASS

FIG. 9